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Wright-Patterson Air Force Base, Ohio

OPTIMAL PLACEMENT MODEL FOR THE
B-52G WEAPONS SYSTEM TRAINER

Franklin E. Hoke, Jr., Captain, USAF

LSSR 83-81

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As a result of the Force Modernization Study, the Strategic Air Command will have its first new generation simulator, the Weapons System Trainer (WST), available in the beginning of 1982. Because of the highly intensive requirements of B-52 training, it had been determined that each B-52 unit would be equipped with a total WST system. While there is agreement with the strategic implications of individual base location for the WST, the necessity of that decision should be questioned. The original research question directed at G model bases was: Can an economically optimum location scheme be determined for the minimum number of WST's necessary to meet training requirements? Consequently, the central objective of this research was the development of a mathematical model which would assure the optimum placement of the WST based on the defined resources, constraints, and economic criteria. The research and generated solutions lend credence to the model as a management tool, in that it permits an objective analysis of alternatives in terms of cost location schemes and number of simulators. It is concluded that the model should provide useful information in future simulator location studies.

LSSR 83-81

OPTIMAL PLACEMENT MODEL
FOR THE
B-52G WEAPONS SYSTEM TRAINER

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Management

By

Franklin E. Hoke, Jr., MS
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September 1981

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Thomas C. Harrington
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CHAPTER I

INTRODUCTION

Background

As reserves of petroleum products began to dwindle and the operational cost of flying began to rise, the Air Force and the Department of Defense (DOD) initiated programs to alleviate the effects of these restrictions. Air Force and DOD planners hypothesized that it was possible to reduce flying hours while maintaining the nation's tactical and strategic capabilities (17:46). This concept was further strengthened by the public awareness of noise and air pollution, aging aircraft and associated increased maintenance costs, and reduced funding to the DOD (12:1). As a result, a goal of a twenty-five percent reduction in flying hours was established by 1981 (6:8).

Because of the reduced flying hour concept, flight simulation has developed into a critical role in aircrew training (14:15). Unfortunately, rising costs are also implicit in simulator procurement (17:51). Due to the reduced buying power of the defense budget, fewer simulators were being purchased during the past several years. This resulted in some Major Commands establishing a regional simulator deployment concept whereby simulators were located at a

central site and shared by other bases within the Command. Furthermore, DOD planners, upon closer examination of the reduced flying hour concept, believed that aircrew proficiency could not be supplemented at the required levels with the present simulator systems (4:2). In the summer of 1975, DOD planning personnel began to examine the available simulator technology and to evaluate plans for future development of simulator systems (4:6). The scope of this research focuses on the new simulator system being developed for the Strategic Air Command's B-52 aircraft, and specifically addresses the basing concept.

Present SAC Technology

The Strategic Air Command (SAC) employs the B-52 Stratofortress as its major piloted element. The B-52 is not only the oldest operational combat aircraft in the U.S. Air Force inventory, but it also has one of the highest cost per flight hour ratios of USAF aircraft (25:17). The reduction of flying hours to SAC was especially critical to the strategic mission and increased utilization of B-52 flight simulators was inevitable. However, it was recognized that with the modernization of the B-52, the current training devices were fast becoming inefficient and obsolete (21:1). These devices employ outdated analog technology and do not provide the total training required within an aircrew simulator training program (21:2). The B-52 Cockpit Procedural Trainers (CPT)

were built in the late 1950s and none of the B-52 simulators incorporate motion or visual queues (4:5).

Future SAC Technology

As a result of the Force Modernization Study, SAC will have its first new generation simulator, known as the Weapons Systems Trainer, available in the beginning of 1982 (21:21). The B-52 sub-systems of the Weapons Systems Trainer (WST) will consist of a computation system and flight, instructor, offensive and defensive stations (21:4-9). This ground based simulator will assume a major role toward satisfying the requirements of maintaining aircrew proficiency in the B-52.

Because of the highly intensive requirements of B-52 training, it has been determined that each B-52 unit will be equipped with a total WST system. The basing plan involves a fixed base vault type facility located in close proximity to alert aircraft. Basing of the simulators is predicated on co-location with the specific B-52 model type (21:21).

Statement of the Problem

While there is agreement with the strategic implications of individual base location for the Strategic Air Command's Weapon Systems Trainer, the necessity of that decision should be carefully investigated. In today's world of rising costs, a contract of this magnitude could easily have initial cost projections which are understated. With

the inevitable demise of the B-52, it is entirely within the scope of the project to plan for a WST placement which is short lived, thus resulting in wasted funds and effort. In order to effectively plan for the WST basing concept, effort should be made to analyze future implications of the location scheme with future usage of the B-52.

At the present time, there appears to be no established procedure to insure that the WST or any other future technology simulators are optimally located from an economic perspective. In many cases, the locations of regional simulators are determined by a subjective staff evaluation involving extensive time and personnel resources (27:2). While this method produces effective results, it is inefficient in terms of resource consumption. Another method for determining simulator placement has been using the input of unit commanders through informal discussions. In this case, the most influential agency usually has precedence (27:2). An objective and economically efficient method is needed to determine the optimal placement of the WST while satisfying aircrew simulator training demand based on the inevitable replacement of the B-52.

Objective

The purpose of this study is to develop and validate a mathematical model that can be used to assist in the determination of the economically optimal location scheme for the

Weapons System Trainer (WST).

Justification

As was previously stated, flight simulator systems are assuming a critical role in aircrew training. Increased emphasis has been placed on efficient acquisition of future simulator systems (14:15). Individuals responsible for the deployment and management of these systems state: "Insufficient quantitative tools exist to determine whether the resultant placement of the simulator systems is economically optimal [27:9]." In most instances, regional deployment of these systems has been done using a purely subjective methodology without quantitative evaluation of operational or life cycle costs. As a result, the final placement of the simulator system cannot be evaluated as to its optimality using an economic criteria.

Nine SAC B-52G units are scheduled to receive ten B-52G Weapon Systems Trainers. Personnel at SAC Headquarters have advocated that each unit should be fully equipped, despite the fact that the B-52 will be replaced in the near future.

> Over the long term - some time after 1995 - when the B-52 fleet's average age will exceed thirty-six years, and its maintainability and supportability will become marginal and extremely costly, the present fleet of more than 350 strategic bombers will have to be replaced in its entirety [24:19].

Even if the B-52 is not totally replaced but only supplemented by a new long range combat aircraft (LRCA), it seems

reasonable to assume that the likelihood of a WST becoming idle at a location is as certain as the LRCA's basing at existing SAC installations. Due to rising transportation and fuel costs, even a slightly less than optimal placement of the WST's will result in needless expenditures of future funds and resources. These expenditures will likely increase at an increasing rate in the coming years and since moving an established system is cost prohibitive, proper placement at the establishment of the program is vital (27:10). In addition, the Strategic Air Command is also procurring five B-52H WST's for operational units. Further, the possibility of a new simulator for the LRCA locations is inevitable. Any improved methodology developed could be used in these future simulator location problems.

An extensive literature review did not reveal that any efforts to analyze simulator placement using a quantitative approach had been fully developed. However, Captains David R. VanDenburg and Jon D. Veith of the Air Force Institute of Technology class of 78B attempted to develop a mathematical model to assist in the placement decision. The model was developed but a suitable computer algorithm could not be found to solve the resulting equations (27:43). Without a quantitative approach to the simulator location problem, WST comparisons of alternative location plans are difficult to validate and the final location strategy may not be economically optimal. A mathematical model would

assist management personnel responsible for the determination of simulator locations and provide a means for cost comparisons of alternative location plans.

Research Question

The question which is addressed in this research is: Can an economically optimum location scheme be determined for the minimum number of WST's necessary to meet training requirements? It is hypothesized that ten simulators located at nine SAC wings provide excess training capacity. If the number of simulators can be reduced, the research question implies that a location scheme must be determined that minimizes both fixed installation costs and variable usage costs while meeting the training requirements.

Summary

As new Weapon Systems Trainers are phased into the SAC operational inventory and present systems are redistributed, optimal placement of these systems should be assured. A quantitative model would assist in the optimal placement of the WST as well as other new simulators and provide managerial personnel a decision aiding basis for evaluation of alternative location strategies. The model could result in more efficient resource allocation in this important area of aircrew training.

Chapter II discusses the model development from

conceptual phase to the selection of a computer algorithm to expedite a solution for optimality.

CHAPTER II

METHODOLOGY

This chapter describes the methodology used in the development of the model selected to determine the economically optimal location scheme for the WST. The chapter begins with several research questions which provided direction and guidance for the investigation. The development of the model is then presented by reviewing appropriate location analysis literature followed by the introduction and definition of variables and parameters essential to the model formulation. The parameterization process, or assignment of values to the defined variables, will then be discussed. The assumptions and known model limitations will then be acknowledged. This will be followed by the formulation of the WST location model. Finally, the selection of a computer algorithm to solve the model and a proposed method of validation will be presented.

RESEARCH QUESTIONS

The following questions were developed to guide the development of the WST location model:

1. What type of model would best satisfy the stated objectives?

2. What variables should be recognized as inherent to the development of this model?

3. What factors will influence the various costs used in the model and how can these costs be estimated?

4. If excess capacity exists in the simulator system, how can the choice of number of simulators and locations be determined and still satisfy the existing demand?

DEVELOPMENT OF THE MODEL

The major issue concerning the WST is the determination of optimal locations. For manufacturers, the problem is broadly categorized into factory or warehouse location. The general objective in choosing a location is to select that site or combination of sites that minimizes the fixed and variable costs (8:40).

One of the complex strategy decisions that must be made by any organization is when to locate a finite number of new facilities, i.e., warehouse, plants, and the like so as to minimize two classes of costs. These costs consist of:

(1) the investment and operating costs of the facilities (10:331), and

(2) the linear distribution costs (11:290).

Location-allocation problems also involve the placement of these new facilities to satisfy a demand at the various locations subject to a capacity limitation on output. The location problem breaks down into several basic questions. These are

(5:239):

(1) How many facilities should there be in a distribution system?

(2) How should the demand be allocated?

(3) Where should the facilities be located?

(4) What size should the facility be in terms of demand throughput?

(5) How should the demand be allocated to the facilities in a distribution system?

A number of location models have been developed that aid in answering all or most of these questions. By necessity, all must be programmed on a large-scale computer for effective use as a management tool. These location models can be classified as (1) algorithmic, (2) simulation, or (3) heuristic types (5:239).

Leon Cooper was the first to coin the phrase "location-allocation"; however his solution was to address the problem of location on a continuous plane, whereas for this research, the locations are to be generated from a finite set of equally acceptable locations (11:290). Ellwein states that the problem is further characterized by requiring the explicit consideration of fixed cost, capacity constraints, and configuration constraints. Fixed costs and capacity constraints are associated with the establishment and operation of the sources, while the configuration constraints restrict the relative placement (11:290).

A mathematical representation of Ellwein's model is stated as follows (11:290):

$$\text{minimize } z = \sum_i \sum_j d_{ij} x_{ij} + \sum_i g_i\Big(\sum_j x_{ij}\Big) + \sum_i f_i y_i$$

subject to

$$\sum_i x_{ij} \geq b_j \qquad j = 1,2,\ldots,n$$

$$\sum_j x_{ij} \leq a_i y_i \qquad i = 1,2,\ldots,m$$

$$\sum_{i \varepsilon s_t} y_i \leq r_t \qquad t = 1,2,\ldots,p$$

$$x_{ij} \geq 0$$

$$y_i = 0 \text{ or } 1$$

The zero-one decision variables y_i indicate whether location i is selected for use; $y_i = 0$ means that the location is not selected and $y_i = 1$ means that it will be used. Each continuous decision variable x_{ij} represents the nonnegative allocation location i supplies to demand point j. The first two constraints state that the demand at each location must be satisfied and the capacity must not be exceeded.

The objective is to minimize an objective function representing the inbound and outbound variable costs plus the fixed cost components. All cost coefficients are nonnegative. Loosely speaking, the problem can be considered one of determining the optimal tradeoff between a large number of facilities with high total fixed and low total variable cost versus a small number of sources with low fixed and high total

variable cost (11:291).

Ellwein's general problem description encompasses a number of specific problems. Examples of several that have received attention in the literature include (11:291): plant location, vendor selection, facility location-allocation, drilling site location and lock box placement. Table 2-1 presents a summary of past work and the characteristics of the location-allocation problem. The table indicates that in many instances, fixed costs are assumed zero, capacity constraints are not considered, or system configurations are ignored (11:291). Assumptions of this kind are inappropriate and oversimplify the problem.

Further analysis by Ellwein and followup researchers such as Akine and Khumawala simplified the objective function to its present expression (3:585).

$$\text{minimize} \sum_i \sum_j C_{ij} X_{ij} + \sum_i F_i Y_i$$

Where Ellwein used an implicit enumeration scheme in conjunction with feasibility optimality tests, Khumawala developed a more efficient computational methodology compared with existing algorithms. The branch and bound solution method proposed by Khumawala is made efficient by generating a sequence of partial assignments and analyzing the completions of each in search of successively better feasible solutions (3:586).

Because of the similarity between the WST placement

Table 2-1

Past Work Location-Allocation Problems (11:291)

Author	Fixed or Nonlinear Costs	Capacity Constraints	System Configuration Constraints	Exact Solution Procedure
Curry and Skeith	no	no	yes	yes
Davis and Ray	yes	yes	no	yes
Drysdale and Sandiford	yes	no	no	no
Efroymson and Ray	yes	no	no	yes
Feldman, Lehrer, and Ray	yes	no	no	no
Healy	yes	no	no	no
Jandy	yes	yes	no	no
Kuehn and Hamburger	yes	no	no	no
Levy	yes	no	no	no
Manne	yes	no	no	no
Marks	yes	yes	no	yes
Sa	yes	yes	no	yes
Spielberg	yes	no	yes	yes
Stanley, Honig, and Gaimen	yes	yes	no	no

and the industrial facility location problems, a linear programming[1] model appeared to be the partial key to a suitable form of model. The second part to the model was to realize that a partial simulator could not be allocated to a location. Therefore a mixed integer programming model appeared to be the best approach. As a first step in using this technique, all variables relevant to the problem must be identified and defined.

Definition of Variables and Parameters

This section defines the variables and parameters incorporated in the WST location model.

1. Fixed Costs (F_i). The fixed cost parameter is any one time expense that remains constant with respect to the installation of a flight simulator at location i. This amount may include any necessary building construction or renovation of existing buildings to house the simulator complex. Also included is the cost to move all associated subsystems of the simulator from its present locations to base i. This cost is expected to be unique to each location.

2. Usage Costs (C_{ij}). Usage cost parameters are the variable costs that fluctuate directly with changes in distances between base j, the user base, and base i, the simulator location. In this research, the figure was deter-

[1]A short discussion of linear programming is presented in Appendix A.

mined as the fuel cost per hour of B-52 flight time converted via mileage data between bases.

3. Capacity (S_i). Capacity is the number of training hours available per year at base i if a simulator is located there. The required annual utilization rate is determined by selecting the maximum usage rate for one of the three separate functions of the WST: the flight station, offensive station, and the defensive station. This selection provides an inherent buffer in training hours available. It will represent the maximum number of hours per year available that can be supported by base i.

4. Demand (D_j). This parameter represents the number of hours of annual training required by crew members assigned to base j. This number can be determined by an examination of current crew availability by base and by application of the Strategic Air Command Operational Concept training requirements. Once again, the highest annual training requirement for crew positions will be selected to provide a buffer.

5. Decision Variable (X_{ij}). This variable represents the quantity of demand allocated from base i to base j for simulator training. The value of X_{ij} will be determined by the constraints imposed upon the final model. Accordingly, this variable is controllable by the decision maker, through the model, since once the simulator locations are chosen, demand is then allocated to minimize usage costs.

6. Decision Variable (Y_i). This decision variable represents the 9 potential simulator locations as shown in Figure 2-1. This variable is also controlled by the decision maker, through the model, since locations are chosen for simulators to minimize fixed and usage costs.

7. Locations (N). This number represents the maximum number of potential simulator locations. It will also define the end product solution to the present research.

Parameterization and Assumptions

The values assigned to the defined parameters, which is referred to as the process of parameterization, were obtained through different sources. The following reintroduces each parameter and discusses the determination of its value.

1. Fixed Costs (F_i). The Fixed Costs for each WST were determined by using the actual line item cost figures plus the given transportation costs contained in the final contract/award to Singer-Link of the Singer Company. Several options were available as to unit price depending upon fiscal year application. The lowest priced option for each WST was selected so that if any savings were realized in the final solution, it would represent the minimum savings. The transportation costs did not change with respect to fiscal year for each location (See Table 2-2).

Figure 2-1

Potential Emulator Locations

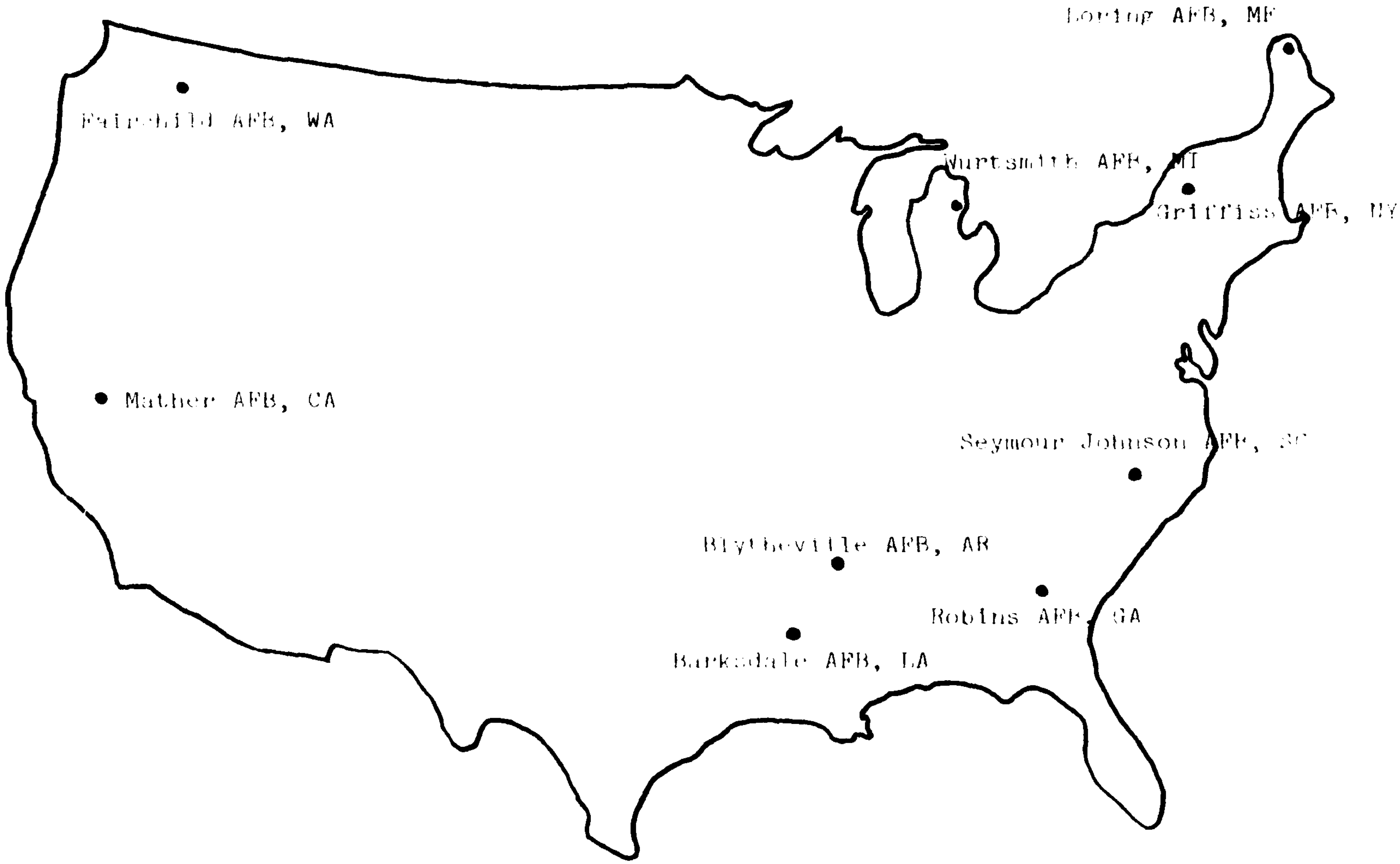

Table 2-2

Total Fixed Costs (1:56-61)

	Base	Unit Cost + Transportation
A	Barksdale	27,458,578 + 162,868
B	Blytheville	13,378,235 + 23,072
C	Seymour Johnson	12,687,840 + 45,154
D	Fairchild	22,827,786 + 111,049
E	Griffiss	13,378,235 + 5,429
F	Loring	12,687,840 + 54,832
G	Mather	13,729,289 + 132,705
H	Robins	13,378,235 + 16,286
I	Wurtsmith	14,474,594 + 16,286

Assumptions:

The first assumption is that the costs of operating a simulator system are the same at any base, once the system is installed.

The second assumption concerns the fixed costs for Wurtsmith AFB. Because of an oversight in the final contract, no information was available for cost figures on Wurtsmith AFB. The figures applied to Wurtsmith are the mean of all the other simulator line item costs plus the transportation cost equal to the cost to Robins AFB, Georgia which is approximately the same distance away from the Singer plant as Wurtsmith.

2. Usage Costs (C_{ij}). This cost was found to be a function of the distance between the bases and the method of transportation used (27:14). Distance measurements were obtained from the Wright-Patterson AFB Accounting and Finance Office (AFO). Using a standard cruise planning figure of 420 knots true airspeed (TAS) and converting it to 483 miles per hour, the one way distances were transformed into time increments. The fiscal year 1981 USAF Cost and Planning Factors pamphlet provided fuel cost per hour for B-52 aircraft. Thus the flying time was converted to a usage cost (See Table 2-3).

Assumptions:

By expeditious scheduling of missions, it would be possible for a user base to include the simulator base as part

Table 2-3

Relationship Between Bases (26)

	Barksdale	Blytheville	Seymour Johnson	Fairchild	Griffiss	Loring	Mather	Robins	Wurtsmith
Barksdale	0	409 (*) .347 (+) 2085 (°)	1046 2.166 5333	2079 4.304 10596	1426 2.952 7268	2035 4.213 10372	1931 3.998 9843	2153 4.458 10976	2292 4.745 11682
Blytheville		0	792 1.640 4037	2013 4.168 10262	1056 2.186 5382	1664 3.445 8482	2127 4.404 10843	542 1.122 2762	836 1.731 4262
Seymour Johnson			0	2625 5.435 13381	663 1.373 3380	1125 2.329 5734	2859 5.919 14573	468 .969 2386	940 1.946 4791
Fairchild				0	2457 5.087 12524	2787 5.770 14206	839 1.737 4277	2480 5.135 12642	1914 3.963 9757
Griffiss					0	660 1.367 3366	2775 5.745 14144	1054 2.182 5372	598 1.238 3048
Loring						0	3294 6.820 16791	1538 3.184 7839	1114 2.306 5677
Mather							0	2563 5.306 13063	2447 5.066 12473
Robins								0	1013 2.097 5163
Wurtsmith									0

* Distance (miles)

\+ Time (hours)

° Cost ($)

of its training flight scenario. For example: Base 1 launches an aircraft on a training sortie. Upon completion of all inflight training, the aircraft lands at Base 2 where it is a user of the simulator facilities. At Base 2, the crew can refly the just completed sortie or prefly the next sortie(s) on the following day. This could easily be accomplished using the present canned mission packages. Upon completion of simulator training and crew rest, the crew would return to home station via a follow on training flight.

Temporary Duty (TDY) expenses would be consistent between bases and need not be included in the analysis.

Takeoff to leveloff and descent to landing distances were excluded in the distance data. These distances were also consistent between bases and would not be relevant especially if the initial usage assumptions were satisfied.

3. Capacity (S_i). The capacity for the WST was obtained from the Technical Considerations of the SAC Operational Concept dated 1 February 1979. The required annual utilization rate for each major subsystem is depicted in Table 2-4. The highest level for B-52G units was the Defensive Station. This utilization rate was 4500 hours annually. Selection of this rate allows a six and two percent buffer in capacity for the flight and offensive stations respectively.

Assumptions:

All simulator systems that will be installed will be operating at the selected capacity.

Table 2-4

Planned Operating Hours Per Year (22:3)

	Flight	Offensive	Defensive
B-52CCTS	4670	4400	4400
B-52G Unit	4250	4400	4500 *
B-52H Unit	4800	5100	4700

* selected research utilization rate

A simulator system can be scheduled for use up to 20 hours per day, six days per week. This will leave 4 hours per day and one day per week for preventive maintenance and/or surge training requirements (22:2).

4. Demand (D_j). The demand figures were calculated using the following equation:

$$D_j = \left[(n_j \times T) + (\overline{n}_j \times T)\right] \overline{N} \times A \qquad \text{(Eq 2.1)}$$

The definition of terms are:

D_j ≡ demand location j

n_j ≡ number of combat ready crews at base j

T ≡ training requirement per Offensive Team from Strategic Air Command Operational Concept; constant 160 hours (See Table 2-5).

$\overline{n}_j$ ≡ number of spare crews ≡ constant 2

$\overline{N}$ ≡ number of simulators at base j. Only Barksdale AFB is receiving more than one simulator.

A ≡ adjustment for Barksdale AFB due to excess usage from 8th Air Force and Combat Evaluation Group Staff ≡ 5% (13).

The results of the calculations are contained in Table 2-6. It is noted that five levels of demand are provided based on crew posture. The current manning posture suggests the 14 crew demand figures be used for model input. However, sensitivity analysis will be used to determine if different location schemes result when demand increases because of additional crew postures.

Table 2-5

Optimum Training Requirements for Existing Training Levels

Including Staff and Spare Crew Members (21:15)

B-52G/H Mission Qualification/Continuation Training

Training Category	Task Frequency	Annual Hours
Pilot/Copilot		
Emergency Procedures	4	12.0
Instruments	4	16.0
Tactical Mission	12	72.0
ORI Preparation	2	8.0
EWO	2	16.0
Instrument Check	1	3.0
60-4 Preparation	1	4.0
60-4	1	4.0
Unit Directed	2	8.0
Totals	29	143.0
Offensive Team		
Tactical Mission	12	72.0
ORI Preparation	2	8.0
EWO	2	16.0
60-4 Preparation	1	4.0
60-4	1	4.0
Unit Directed	2	8.0
Cruise Missile Training	4	16.0
AGM-69/Low Bomb	2	8.0
Celestial	2	8.0
ORI Procedures	2	8.0
Unit Option (Specialized)	2	8.0
Totals	32	160.0
Defensive Team		EW/Gunner
Tactical Mission	12	72.0/72.0
ORI Preparation	2	8.0/ 8.0
EWO	2	16.0/16.0
60-4 Preparation	1	4.0/ 4.0
60-4	1	4.0/ 4.0
Unit Directed	2	8.0/ 8.0
EWO Profile Exercise	4	-/ 8.0
FIE Profile	2	8.0/ 8.0
Fireout Profile	2	-/ 4.0
Contingency Profile	4	-/ 8.0
Threat Laboratory	4	16.0/ -
Emergency Procedures	2	6.0/ 6.0
Totals	28/34	142.0/146.0

Table 2-6

Calculation of Aircrew Demand

Demand (D_j)

$$D_j = \left[(n_j \times T) + (\bar{n}_j \times T)\right] \bar{N} \times A \qquad \text{(Eq 2.1)}$$

<u>Hours per Number of Crews</u>[2]

Base	12 + 2	14 + 2	16 + 2	18 + 2	20 + 2
Barksdale	9724	5376	6048	6729	7329
Others	2240	2688	2880	3200	3520

---

[2]The base number of fully integrated combat ready crews is the first number. A fully integrated combat ready crew is one in which all members are Emergency War Order/Single Integrated Operational Plan (EWO/SIOP) qualified and designated by written orders to be members of one specific crew. The plus two in each case represents an additional spare crew capability.

Assumptions:

The current manning assigned to each base is constant throughout the command. Also the annual training requirements will not change in the near future and if they do, proportionality will exist.

5. Locations (N). For the ten simulators available, nine locations have been defined other than Castle AFB which is the Combat Crew Training School (See Table 2-7).

Assumptions:

All bases designated as potential sites for WST simulators will remain so designated.

Model Form

The extensive literature review indicated that the capacitated warehouse (plant) location problem was very similar to the WST location problem with respect to model formulation. Mathematically, this problem in its simplest form can be formulated as a mixed integer program as follows, with N potential locations and m customers (3:585):

$$\text{Minimize Cost } (Z) = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij} + \sum_{i=1}^{n} F_i Y_i \qquad \text{(Eq 2.2)}$$

Subject to the following constraints:

$$\sum_{i=1}^{n} X_{ij} = D_j \quad \text{for } j = 1,\ldots,9 \quad \text{(Demand)} \quad \text{(Eq 2.3)}$$

$$\sum_{j=1}^{m} X_{ij} \leq S_i Y_i \quad \text{for } i = A,\ldots,I \quad \text{(Capacity)} \quad \text{(Eq 2.4)}$$

$$\sum_{i=1}^{n} Y_i \leq N \qquad \text{(Locations)} \quad \text{(Eq 2.5)}$$

$$Y_i = \begin{cases} 1 & \text{location } i \text{ open} \\ 0 & \text{location } i \text{ closed} \end{cases} \qquad \text{(Integer)}$$

$$X_{ij},\ C_{ij},\ F_i,\ S_i,\ D_j,\ Y_i,\ N \geq 0 \qquad \text{(Non-negativity)}$$

The indicated variables are as defined in the previous sections, where:

N ≡ total number of potential facilities

X_{ij} ≡ quantity of demand allocated from i to j

C_{ij} ≡ variable cost of usage/transportation from i to j

F_i ≡ fixed costs for base i

D_j ≡ units demanded at base j

S_i ≡ capacity of facility i

Limitations

The following model characteristics have been recognized as model limitations:

1. The solution generated by the model is economically optimal within the identifiable constraints. Any subjective factors such as unit commander preferences have not been included in the model structure.

2. The model developed is only intended to be used as a tool to aid in the decision making process of site selection. There is no basis for the model to replace the human thought impact on the final decision.

Table 2-7

Ready for Training Dates (RFT) (2)

Number of WST	Base	B-52 model	Dates
2	Barksdale	G	1 Dec 1982
1	Blytheville	G	1 Mar 1983
OSMT	Castle	Offensive station two each G/H	1 Aug 1983
SSC	Castle	Software Support	
1	Seymour Johnson	G	1 Dec 1983
1	Fairchild	G	1 Feb 1984
1	Griffiss	G	1 Apr 1984
1	Loring	G	1 Aug 1984
1	Grand Forks	H	1 June 1984
1	Mather	G	1 June 1985
1	Robins	G	1 Sept 1985
1	Ellsworth	H	1 Dec 1984
1	Ellsworth	H	1 Mar 1985
1	Wurtsmith	G	1 Jun 1986
1	Castle	G	1 Sept 1986
1	K. I. Sawyer	H	1 Dec 1985
1	Minot	H	1 Mar 1986

SELECTION OF THE COMPUTER ALGORITHM

The model, as previously discussed, will take on the form:

$$\text{Minimize Cost } (Z) = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij} + \sum_{i=1}^{n} F_i Y_i \qquad \text{(Eq 2.2)}$$

subject to capacity and demand constraints. A small scale problem of this type could be solved using manual compilations. However, as the problem becomes more complex when variables and constraints are added, the necessity of the use of a computer becomes essential to the generation of a final solution (23:225). Consequently, as the model was in the development stage and constraints were emerging, a search was conducted for an integer programming algorithm designed to solve successively restricted variants of the standard linear program problem. One of these would be selected and modified for use in the solution generation.

PROPOSED MODEL VALIDATION

Validation

The validation stage, which insures that the behavior of the model agrees with that of the real system, is a critically important process (19:210). However, while validation is very important, it is also very difficult to do precisely since "there is no such thing as the 'test' for validity [19:29]." The most obvious method to validate a

model is to statistically compare model output to that of the real system (19:227). In this research, this method was not possible since the WST placement has not been fulfilled. Another method of validation, which will be relied upon in this research, is to have the model structure, parameterization, and output evaluated by people knowledgeable with the system. Shannon states that (19:236):

> I firmly believe that the professional judgement of the people most intimately familiar with the design and operation of a system is more valuable and valid than any statistical test yet devised.

Prior to finalization of this thesis, the contents shall be forwarded to the Strategic Systems System Program Office (SPO) and the Simulator Systems SPO to take advantage of the knowledge and insight of those familiar with the system under study.

SUMMARY

This research is an attempt to develop a mathematical model which can be used to assist in the determination of the optimal placement of the WST specifically and future simulator systems in general. Background research indicates that a mixed integer linear programming relationship of the form:

$$\text{Minimize Cost } (Z) = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij} + \sum_{i=1}^{n} F_i Y_i$$

subject to various demand and capacity constraints will

provide an effective basis for the model. This study was to develop and validate the model and a computer algorithm capable of solving the system of equations developed.

After validation, the model would be used as a tool to assist in the determination of the optimal location and quantity of the WST. Subsequent efforts in simulator placement for new generation aircraft may also find the model useful.

Chapter III presents the actual data used for the final model and the resultant solution to the WST placement problem. Sensitivity analysis results will also be provided as to the influence of demand on the solution.

CHAPTER III

ANALYSIS

This chapter presents the results obtained from the study of the WST location problem using an optimal placement model. General model development is first described, followed by a discussion of the specific model formulated for the simulator placement problem. The computerized algorithm used to solve the location problem is then presented with analysis of the solution. Finally, the results of the sensitivity analysis, which was incorporated to determine the effects of demand level changes on location strategies, are reported.

MODEL DEVELOPMENT

Formulation

After consideration of several alternative model forms, a mixed integer linear programming structure was selected because it best fit the generated problem (7:274-275). The general model developed is as follows:

Objective function:

$$\text{Minimize Costs } (Z) = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij} + \sum_{i=1}^{n} F_i Y_i \qquad \text{(Eq 2.2)}$$

Subject to:

$$\sum_{i=1}^{n} X_{ij} = D_j \qquad j = 1,\ldots,m \qquad \text{(Demand)} \qquad \text{(Eq 2.3)}$$

$$\sum_{j=1}^{m} X_{ij} \leq S_i Y_i \qquad i = 1,\ldots,n \qquad \text{(Capacity)} \qquad \text{(Eq 2.4)}$$

$$\sum_{i=1}^{m} Y_i \leq N \qquad \text{(Locations)} \qquad \text{(Eq 2.5)}$$

$$X_{ij},\ C_{ij},\ Y_i,\ F_i,\ D_j,\ S_i,\ N \geq 0 \qquad \text{(Non-negativity)}$$

$$Y_i = 0,\ 1 \qquad i = 1,\ldots,n \qquad \text{(Integer)}$$

Definition of Variables

X_{ij} is a decision variable representing the quantity of demand allocated from base i to base j for simulator training.

C_{ij} is the usage costs that fluctuate directly with changes in distance between base i and base j for simulator training.

Y_i is a decision variable equal to one if base i is chosen as a simulator site and zero otherwise.

F_i is the fixed costs to activate base i as a simulator site. This cost includes any construction and installation of the simulator or renovation of existing buildings. The cost is a one time charge which would be unique to each location.

S_i represents the maximum capacity of training hours available annually at location i.

The parameter D_j represents the number of hours required annually for simulator training by crew members at

base j.

Specific Application

The general model was translated into a specific formulation to analyze the future placement of the B-52G Weapon System Trainer (WST) and determine if an economically optimum location scheme could be generated. The objective function and constraints of the formulation are given below:

$$\text{Minimize Cost } (Z) = \sum_{i=1}^{9} \sum_{j=1}^{9} C_{ij} X_{ij} + \sum_{i=1}^{9} F_i Y_i \qquad \text{(Eq 3.1)}$$

Subject to

$$\sum_{j=1}^{9} X_{ij} \leq D_j \qquad j = 1,\ldots,9 \qquad \text{(Eq 3.2)}$$

$$\sum_{i=1}^{9} X_{ij} - S_i Y_i \leq 0 \qquad i = 1,\ldots,9 \qquad \text{(Eq 3.3)}$$

$$\sum_{i=1}^{9} Y_i \leq 9 \qquad \text{(Eq 3.4)}$$

$$Y_i = 0,1 \qquad i = 1,\ldots,9$$

$$X_{ij},\ C_{ij},\ Y_i,\ F_i \geq 0$$

Because there are nine bases involved, the system of equations contains 81 possible X_{ij} values, 81 C_{ij} values, 9 F_i values, and 9 Y_i values. The system thus expands into a series of 20 equations involving 90 variables and 90 constants.

Computer Algorithm

A Multi Purpose Optimization System (MPOS) computer

program was used to solve the formulated WST location problem.

> A person with an optimization problem is especially eager to have dependable computer programs requiring a minimum of concern for system specifics outside the scope of his/her primary interest. Most commercial mathematical programming (MP) systems, such as IBM's MPSX or CDC's APEX, are directed at the solution of very large problems stemming from large industrial bases. This software is proprietary and expensive. More often than not, their documentation is not designed for usage by the novice [9:1].
>
> Multi Purpose Optimization System (MPOS) is an integrated system of computer programs to solve optimization problems on CDC 6000/CYBER computers. Because of its simple structure and repertoire of algorithms, MPOS has been extensively used by students in economics, engineering and management [9:1].
>
> When using the MPOS computer software, analysts specify the appropriate control phases, objective function, constraints, and bounds in English and Algebraic notation and then access one of the many available algorithms [9:1].

Of the three integer programming algorithms available in MPOS: BBMIP, DSZ1IP, and GOMORY, BBMIP (Branch and Bound Mixed Integer Program)[3] was selected because of its adaptability to the WST problem's objective function and constraints. The general variant of the standard linear programming problem for BBMIP is (9:47):

Minimize (or maximize) the objective function

$$Z = c^1 x + \bar{c}^1 y$$

Subject to the constraints

$$Ax + \bar{A}y \begin{pmatrix} \le \\ = \\ \ge \end{pmatrix} b$$

---

[3] Appendix B presents an explanation of the algorithm taken directly from (20).

$$0 \leq x \leq U$$

$$0 \leq y \leq \overline{U}$$

where

c, x, U are vectors of n_1 components

c, y, $\overline{U}$ are vectors of $n - n_1$ components

b is a vector of m components

A is $m \times n_1$

$\overline{A}$ is $m \times (n - n_1)$

The computational procedure for BBMIP is briefly described as follows (9:48):

> BBMIP employs a branch and bound algorithm implemented by Shareshian and based upon the Land and Doig method as extended by Drieback to solve mixed integer problems of limited size. The linear programming minimization problem is first solved without regard to integrality constraints; from this point on, the program proceeds as if to enumerate the set of all possible mixed integer solutions by sequentially constraining each integer variable and in turn to an integer value within its range. A dual-simplex linear programming algorithm is used as a bound establishing mechanism immediately after each integer variable is constrained.

The total set of all possible solutions available for the mixed integer problem is given by the equation 2^m-1, where m equals the number of facility locations (16:238).

SIMULATOR PLACEMENT MODEL SOLUTION

Model Expansion

To analyze the simulator placement problem, equations 3.1 through 3.4 were specified in the following form during the parameterization process:

Minimize:

$$
\begin{aligned}
Z = {} & 2085X_{A2} + 5333X_{A3} + 10596X_{A4} + 7268X_{A5} + 10375X_{A6} + \\
& 9843X_{A7} + 10976X_{A8} + 11682X_{A9} + 2035X_{B1} + 4037X_{B3} + \\
& 10262X_{B4} + 5382X_{B5} + 8482X_{B6} + 10843X_{B7} + 2762X_{B8} + \\
& 4262X_{B9} + 5333X_{C1} + 4037X_{C2} + 13381X_{C4} + 3380X_{C5} + \\
& 5734X_{C6} + 14573X_{C7} + 2386X_{C8} + 4791X_{C9} + 10596X_{D1} + \\
& 10262X_{D2} + 13381X_{D3} + 12524X_{D5} + 14206X_{D6} + 4277X_{D7} + \\
& 12642X_{D8} + 9757X_{D9} + 7268X_{E1} + 5382X_{E2} + 3380X_{E3} + \\
& 12524X_{E4} + 3366X_{E6} + 14144X_{E7} + 5372X_{E8} + 3048X_{E9} + \\
& 10372X_{F1} + 8482X_{F2} + 5734X_{F3} + 14206X_{F4} + 3366X_{F5} + \\
& 16791X_{F7} + 7839X_{F8} + 5677X_{F9} + 9843X_{G1} + 10843X_{G2} + \\
& 14573X_{G3} + 4277X_{G4} + 14144X_{G5} + 16791X_{G6} + 13063X_{G8} + \\
& 12473X_{G9} + 10976X_{H1} + 2762X_{H2} + 2386X_{H3} + 12642X_{H4} + \\
& 5372X_{H5} + 7839X_{H6} + 13063X_{H7} + 5163X_{H9} + 11682X_{I1} + \\
& 4262X_{I2} + 4791X_{I3} + 9757X_{I4} + 3048X_{I5} + 5677X_{I6} + \\
& 12473X_{I7} + 5163X_{I8} \\
& + 27{,}621{,}446Y_A + 13{,}401{,}307Y_B + 12{,}732{,}994Y_C \\
& + 22{,}938{,}835Y_D + 13{,}383{,}664Y_E + 12{,}742{,}672Y_F \\
& + 13{,}861{,}994Y_G + 13{,}510{,}994Y_H + 14{,}490{,}880Y_I \qquad \text{(Eq 3.5)}
\end{aligned}
$$

Subject to:

Demand Constraints

Demand Center

A: $X_{A1} + X_{B1} + X_{C1} + X_{D1} + X_{E1} + X_{F1} + X_{G1} + X_{H1} + X_{I1} = 5376$ (Eq 3.6)

B: $X_{A2} + X_{B2} + X_{C2} + X_{D2} + X_{E2} + X_{F2} +$

$$X_{G2} + X_{H2} + X_{I2} = 2688 \qquad \text{(Eq 3.7)}$$

C: $$X_{A3} + X_{B3} + X_{C3} + X_{D3} + X_{E3} + X_{F3} + X_{G3} + X_{H3} + X_{I3} = 2688 \qquad \text{(Eq 3.8)}$$

D: $$X_{A4} + X_{B4} + X_{C4} + X_{D4} + X_{E4} + X_{F4} + X_{G4} + X_{H4} + X_{I4} = 2688 \qquad \text{(Eq 3.9)}$$

E: $$X_{A5} + X_{B5} + X_{C5} + X_{D5} + X_{E5} + X_{F5} + X_{G5} + X_{H5} + X_{I5} = 2688 \qquad \text{(Eq 3.10)}$$

F: $$X_{A6} + X_{B6} + X_{C6} + X_{D6} + X_{E6} + X_{F6} + X_{G6} + X_{H6} + X_{I6} = 2688 \qquad \text{(Eq 3.11)}$$

G: $$X_{A7} + X_{B7} + X_{C7} + X_{D7} + X_{E7} + X_{F7} + X_{G7} + X_{H7} + X_{I7} = 2688 \qquad \text{(Eq 3.12)}$$

H: $$X_{A8} + X_{B8} + X_{C8} + X_{D8} + X_{E8} + X_{F8} + X_{G8} + X_{H8} + X_{I8} = 2688 \qquad \text{(Eq 3.13)}$$

I: $$X_{A9} + X_{B9} + X_{C9} + X_{D9} + X_{E9} + X_{F9} + X_{G9} + X_{H9} + X_{I9} = 2688 \qquad \text{(Eq 3.14)}$$

Capacity Constraints

Facility

A: $$X_{A1} + X_{A2} + X_{A3} + X_{A4} + X_{A5} + X_{A6} + X_{A7} + X_{A8} + X_{A9} - 9000Y_A \le 0 \qquad \text{(Eq 3.15)}$$

B: $$X_{B1} + X_{B2} + X_{B3} + X_{B4} + X_{B5} + X_{B6} + X_{B7} + X_{B8} + X_{B9} - 4500Y_B \le 0 \qquad \text{(Eq 3.16)}$$

C: $$X_{C1} + X_{C2} + X_{C3} + X_{C4} + X_{C5} + X_{C6} + X_{C7} + X_{C8} + X_{C9} - 4500Y_C \le 0 \qquad \text{(Eq 3.17)}$$

D: $$X_{D1} + X_{D2} + X_{D3} + X_{D4} + X_{D5} + X_{D6} + X_{D7} + X_{D8} + X_{D9} - 4500Y_D \le 0 \qquad \text{(Eq 3.18)}$$

E: $$X_{E1} + X_{E2} + X_{E3} + X_{E4} + X_{E5} + X_{E6} + X_{E7} + X_{E8} + X_{E9} - 4500Y_E \le 0 \quad \text{(Eq 3.19)}$$

F: $$X_{F1} + X_{F2} + X_{F3} + X_{F4} + X_{F5} + X_{F6} + X_{F7} + X_{F8} + X_{F9} - 4500Y_F \le 0 \quad \text{(Eq 3.20)}$$

G: $$X_{G1} + X_{G2} + X_{G3} + X_{G4} + X_{G5} + X_{G6} + X_{G7} + X_{G8} + X_{G9} - 4500Y_G \le 0 \quad \text{(Eq 3.21)}$$

H: $$X_{H1} + X_{H2} + X_{H3} + X_{H4} + X_{H5} + X_{H6} + X_{H7} + X_{H8} + X_{H9} - 4500Y_H \le 0 \quad \text{(Eq 3.22)}$$

I: $$X_{I1} + X_{I2} + X_{I3} + X_{I4} + X_{I5} + X_{I6} + X_{I7} + X_{I8} + X_{I9} - 4500Y_I \le 0 \quad \text{(Eq 3.23)}$$

Bounds:

$$Y_A + Y_B + Y_C + Y_D + Y_E + Y_F + Y_G + Y_H + Y_I \le 9 \quad \text{(Eq 3.24)}$$

$$X_{ij} \ge 0 \quad \text{(Eq 3.25)}$$

$$Y_i = \begin{cases} 0 \text{ if location i closed} \\ 1 \text{ if location i open} \end{cases}$$

There are 511 possible solution combinations (2^9-1) to the WST placement problem. For example, one solution alternative would be placing simulators at Barksdale, Griffiss, Mather, and Fairchild and determining the resulting allocation of the demand for training. For this problem, optimality was established at iteration 185 using BBMIP. Total computer time for the problem was 4.58 seconds. The optimal solution is presented in the matrix in Figure 3-1.

Analysis of Figure 3-1 indicates the following results:

A uses 5376 hours at location A (X_{A1} = 5376)

Figure 3-1

Fourteen Crews Assignment Matrix

* Potential N = 9 (unused capacity)

To \ From	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	0 5376	2085 2688	5333	10596 816	7268	10372	9843	10976	11682	0 120	9000
B Blytheville	2085	0	4037	10262	5382	8482	10843	2762	4262	0	4500
C Seymour J.	5333	4037	0 2688	13381	3380	5734	14573	2386 1812	4791	0	4500
D Fairchild	10596	10262	13381	0	12524	14206	4277	12642	9757	0	4500
E Griffiss	7268	5382	3380	12524	0	3366	14144	5372	3048	0	4500
F Loring	10372	8482	5734	14206	3366 1812	0 2688	16791	7839	5677	0	4500
G Mather	9843	10843	14573	4277 1812	14144	16791	0 2688	13063	12473	0	4500
H Robins	10976	2762	2386	12642	5372	7839	13063	0	5163	0	4500
I Wurtsmith	11682	4262	4791	9757 60	3048 876	5677	12473	5163 876	0 2688	0	4500
Demand	5376	2688	2688	2688	2688	2688	2688	2688	2688	* 26880	45000 / 45000

B uses 2688 hours at location A (X_{A2} = 2688)

D uses 816 hours at location A (X_{A4} = 816)

C uses 2688 hours at location C (X_{C3} = 2688)

H uses 1812 hours at location C (X_{C8} = 1812)

E uses 1812 hours at location F (X_{F5} = 1812)

F uses 2688 hours at location F (X_{F6} = 2688)

D uses 1812 hours at location G (X_{G4} = 1812)

G uses 2688 hours at location G (X_{G7} = 2688)

I uses 2688 hours at location I (X_{I9} = 2688)

H uses 876 hours at location I (X_{I8} = 876)

D uses 60 hours at location I (X_{I4} = 60)

E uses 876 hours at location I (X_{I5} = 876)

A has an excess capacity (slack) = 120 hours

Note: $Y_A = 1$, $Y_B = 0$, $Y_C = 1$, $Y_D = 0$, $Y_E = 0$, $Y_F = 1$, $Y_G = 1$, $Y_H = 0$, $Y_I = 1$.

The solution indicates that five simulators located at Barksdale, Seymour Johnson, Loring, Mather, and Wurtsmith results in minimizing total fixed and usage costs while meeting demand and capacity constraints.

The objective function = total fixed cost + total usage cost

= \$81,449,986 + \$40,197,996

= \$121,641,982

Sensitivity Analysis

After generation of the optimal solution, sensitivity analysis was performed on the demand constraints based on a

function of combat crew availability. As was discussed in Chapter II, the sensitivity analysis would span a crew force of twelve fully integrated combat ready crews plus two spare ready crews, to twenty fully integrated combat ready crews plus two spare crews. This analysis would illustrate if different location schemes result when demand changes.

To analyze the sensitivity to demand, the right hand sides of equations 3.6 through 3.14 were changed to reflect the respective demand levels shown in Table 2-6. All other model variables, parameters, and equations remained the same.

The results of the sensitivity analysis are presented in Table 3-1 and Figures 3-2 through 3-5.

SUMMARY

This chapter presented the results obtained from research into the WST placement problem developed in Chapters I and II. Through the use of the BBMIP algorithm contained in MPOS, an optimal solution to the developed model was generated. Sensitivity analysis conducted on the demand constraint revealed the limits of the location scheme.

Chapter IV discusses the conclusions drawn from the generated optimal solution. Validation of the model and recommendations for further research will also be presented.

Table 3-1

Sensitivity Analysis

	Twelve Crews	Sixteen Crews	Eighteen Crews	Twenty Crews
Optimality Established at iteration	353	191	93	76
Computer Time (sec)	7.462	6.324	3.072	1.379
Simulators located at	Barksdale	Barksdale	Barksdale	Barksdale
	Seymour J.	-	Seymour J.	Seymour J.
	Griffiss	Griffiss	-	Griffiss
	Loring	Loring	Loring	Loring
	Mather	Mather	Mather	Mather
	-	Robins	Robins	Robins
	-	Wurtsmith	Wurtsmith	Wurtsmith
	-	-	Fairchild	Fairchild
Objective Function				
Total Fixed Costs	80,342,770	95,611,650	117,898,200	131,283,480
Total Usage Costs	26,423,040	33,351,480	17,660,055	9,821,923
Total Costs	$106,765,810	$128,963,130	$135,558,255	$141,105,403
Reference:	Figure 3-2	Figure 3-3	Figure 3-4	Figure 3-5

Figure 3-2

Twelve Crews Assignment Matrix

* Potential N = 9 (unused capacity)

From / To	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	0 4724	2085 2240	5333	10596	7268	10372	9843	10976	11682	0 2036	9000
B Blytheville	2085	0	4037	10262	5382	8482	10843	2762	4262	0	4500
C Seymour J.	5333	4037	0 2240	13381	3380	5734	14573	2386 2240	4791	0 20	4500
D Fairchild	10596	10262	13381	0	12524	14206	4277	12642	9757	0	4500
E Griffiss	7268	5382	3380	12524	0 2240	3366	14144	5372	3048 2240	0 20	4500
F Loring	10372	8482	5734	14206	3366	0 2240	16791	7839	5677	0 2260	4500
G Mather	9843	10843	14573	4277 2240	14144	16791	0 2240	13063	12473	0 20	4500
H Robins	10976	2762	2386	12642	5372	7839	13063	0	5163	0	4500
I Wurtsmith	11682	4262	4791	9757	3048	5677	12473	5163	0	0	4500
Demand	4724	2240	2240	2240	2240	2240	2240	2240	2240	* 22356	45000 / 45000

Figure 3-3

Sixteen Crews Assignment Matrix

* Potential N = 9 (unused capacity)

From To	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	0 6048	2085 2880	5333	10596	7268	10372	9843	10976	11682	0 72	9000
B Blytheville	2085	0	4037	10262	5382	8482	10843	2762	4262	0	4500
C Seymour J.	5333	4037	0	13381	3380	5734	14573	2386	4791	0	4500
D Fairchild	10596	10262	13381	0	12524	14206	4277	12642	9757	0	4500
E Griffiss	7268	5382	3380 1260	12524	0 2880	3366	14144	5372	3048	0 360	4500
F Loring	10372	8482	5734	14206	3366	0 2880	16791	7839	5677	0 1620	4500
G Mather	9843	10843	14573	4277 1620	14144	16791	0 2880	13063	12473	0	4500
H Robins	10976	2762	2386 1620	12642	5372	7839	13063	0 2880	5163	0	4500
I Wurtsmith	11682	4262	4791	9757 1260	3048	5677	12473	5163	0 2880	0 360	4500
Demand	6048	2880	2880	2880	2880	2880	2880	2880	2880	* 15912	45000 / 45000

Figure 3-4

Eighteen Crews Assignment Matrix

* Potential N = 9 (unused capacity)

To \ From	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	0 6720	2085 2280	5333	10596	7268	10372	9843	10976	11682	0	9000
B Blytheville	2085	0	4037	10262	5382	8482	10843	2762	4262	0	4500
C Seymour J.	5333	4037	0 3200	13381	3380 600	5734	14573	2386	4791	0 700	4500
D Fairchild	10596	10262	13381	0 3200	12524	14206	4277	12642	9757	0 1300	4500
E Griffiss	7268	5382	3380	12524	0	3366	14144	5372	3048	0	4500
F Loring	10372	8482	5734	14206	3366 1300	0 3200	16791	7839	5677	0	4500
G Mather	9843	10843	14573	4277	14144	16791	0 3200	13063	12473	0 1300	4500
H Robins	10976	2762 920	2386	12642	5372	7839	13063	0 3200	5163	0 380	4500
I Wurtsmith	11682	4262	4791	9757	3048 1300	5677	12473	5163	0 3200	0	4500
Demand	6720	3200	3200	3200	3200	3200	3200	3200	3200	* 12680	45000 / 45000

Figure 3-5

Twenty Crews Assignment Matrix

* Potential N = 9 (unused capacity)

From / To	A	B	C	D	E	F	G	H	I	Slack	Capacity
A Barksdale	0 7392	2085 1608	5333	10596	7268	10372	9843	10976	11682	0	9000
B Blytheville	2085	0	4037	10262	5382	8482	10843	2762	4262	0	4500
C Seymour J.	5333	4037 932	0 3520	13381	3380	5734	14573	2386	4791	0 48	4500
D Fairchild	10596	10262	13381	0 3520	12524	14206	4277	12642	9757	0 980	4500
E Griffiss	7268	5382	3380	12524	0 3520	3366	14144	5372	3048	0 980	4500
F Loring	10372	8482	5734	14206	3366	0 3520	16791	7839	5677	0 980	4500
G Mather	9843	10843	14573	4277	14144	16791	0 3520	13063	12473	0 980	4500
H Robins	10976	2762 980	2386	12642	5372	7839	13063	0 3520	5163	0	4500
I Wurtsmith	11682	4262	4791	9757	3048	5677	12473	5163	0 3520	0 980	4500
Demand	7392	3520	3520	3520	3520	3520	3520	3520	3520	* 9448	45000 / 45000

CHAPTER IV

CONCLUSIONS, VALIDATION, AND RECOMMENDATIONS

This final chapter discusses the conclusions drawn from research into the WST location problem along with the validation of the model and recommendations for future research. Initially the objectives of the research will be reviewed. Then a discussion of the solution obtained in Chapter III will be addressed. In the validation section, comments from appropriate sources concerning the value of the model will be presented. The final section provides a listing of recommendations for further reserach.

CONCLUSIONS

Objective

As was previously stated in Chapter I, flight simulator systems are assuming a critical role in aircrew training. However, it was recognized that with the modernization of the B-52, the current training devices employed by the Strategic Air Command were fast becoming inefficient and obsolete. As a result of the Force Modernization Study, SAC will have its first new generation simulator, the Weapons Systems Trainer, available in the beginning of 1982. Because of the highly intensive requirements of B-52 training, it had been

determined that each B-52 unit would be equipped with a total WST system. While there is agreement with the strategic implications of individual base location for the SAC WST, the necessity of that decision should be questioned.

The original research question was: Can an economically optimum location scheme be determined for the minimum number of WSTs necessary to meet training requirements? It was hypothesized that excess training capacity might exist with ten simulators located at nine locations. Research presented in Chapter II supported this hypothesis. This being the case it is possible to reduce the programmed number of simulators and provide the capacity to meet training requirements. Consequently, the central objective of this research was the development of a mathematical model which would assume the optimal placement of the WST based on the defined resources, constraints, and economic criteria. This implies that the model would minimize both fixed installation costs and variable usage costs while meeting the training requirements. A quantitative model would assist in the optimal placement of the WST as well as other new simulators and provide managerial personnel a decision aiding basis for evaluation of alternative location strategies. The model would also provide budgetary estimates during the early formulation stages.

Chapter II discussed several research questions which aided in the development of the WST location model. During

the development of the model, background literature disclosed the similarity between industrial factory or warehouse location studies and the WST location problem The location problem breaks down into several basic questions:

(1) How many facilities should be selected?

(2) How should the demand be allocated?

(3) Where should the facilities be located?

A number of location models have been developed that aid in answering all or most of these questions.

Studies by Ellwein, as extended by Khumawala and Akine, presented an analysis which appeared to be the key to a suitable form of model for this research. A mixed integer programming expression was the resultant approach (see equations 2.2 through 2.5 in Chapter II). By approaching the simulator placement problem from a cost analysis involving fixed costs and variable usage costs, it was believed that the model would enable decision makers to view the problem with respect to total costs.

Results Obtained

A mathematical model for simulator placement was developed and translated into a specific formulation. The system expanded into a series of 20 equations involving 90 variables and 90 constants. An integer programming algorithm available in the Mathematical Programming Optimization System (MPOS) was selected because of its adaptability to the WST problem.

Specific analysis was accomplished by considering the simulator training requirements for a crew force of 14 combat ready crews plus 2 spare crews because of the present manning situation in SAC. An optimal solution was generated on the 185th iteration of the computer algorithm. Based on the demand and capacity constraints, the optimal solution resulted in the placement of six simulators at five locations. The bases chosen were Barksdale, Seymour Johnson, Loring, Mather, and Wurtsmith. The bases not selected as simulator locations were Blytheville, Fairchild, Griffiss, and Robins. Crew members at these bases would travel to a designated WST location for training, if the recommended location scheme is adopted. The total cost, including fixed and variable components considered over a four year period, for the optimal solution was $121,641,982 compared to $144,584,790 (total fixed costs only) for the proposal to place simulators at each of the B-52 units locations. Thus the minimum total savings would be $22,942,808. If the problem were analyzed strictly from the standpoint of fixed costs, the optimal solution total fixed costs would equal $81,449,986 or a total savings of $63,140,804. It is important to note that even with this reduced number of simulators, Barksdale still had excess capacity (120 hours) available for additional simulator training (See Figure 3-1).

When sensitivity analysis was performed to determine if different location schemes would be generated when the

demand changed, a reduced number of WSTs still resulted with the associated savings. Table 4-1 is a summary of cost savings based on the results disclosed in Table 3-1.

Examination of the sensitivity analysis results presented in Table 3-1 revealed some interesting insights into the WST location problem. When the demand for simulator training was changed by varying the number of base crews from fourteen to twenty crews, five locations always appeared in the solution. These bases were: Barksdale, Loring, Mather, Robins, and Wurtsmith. This result should give full confidence in these bases being selected for the WST. Blytheville was never selected as a site for the trainer in the sensitivity analysis models. This indicates a lack of confidence in selecting Blytheville as a WST site.

The research and generated solutions lend credence to the model as a management tool, in that it permits an objective analysis of alternatives in terms of cost location schemes and number of simulators. It is concluded that the model should provide useful information in future simulator location studies.

VALIDATION

As was previously documented, the validation process is very difficult to do precisely because there exists no "test" for validity. Because it was not possible to statistically compare the developed model output to that of the

Table 4-1

Analysis of Costs

Base Number of Crews	Number of Simulators	Total Fixed Costs	Total Variable Costs	Total Costs	Savings with respect to Total Fixed Costs	Savings with respect to Total Costs
12	6	80,342,770	26,423,040	106,765,810	64,242,020	37,818,980
14	6	81,449,986	40,197,996	121,647,982	63,140,804	22,942,808
16	7	95,611,650	33,351,480	128,963,130	48,973,140	15,621,660
18	8	117,898,200	17,660,055	135,558,255	26,686,590	9,026,535
20	9	131,283,480	9,821,923	141,105,403	13,301,310	3,479,384
N/A	10	144,584,790	N/A	144,585,790	N/A	N/A

real system, the model structure, parameterization, and output would be validated using Shannon's methodology as was described in Chapter II. Shannon states that the best judge of validity is one who is intimately familiar with the system. The following presents statements ascertaining the validity of the WST location model:

Colonel James A. Lee, USAF. Director of Program Management, Deputy for Simulators, Wright-Patterson AFB, OH.:

> The developed model should serve as an additional aid in determining the number and placement of simulator devices. Recommend the model and results be provided to planning/requirements staffs at MAC, SAC, TAC Headquarters.

Dick Buvens. Sperry Flight Systems, Defense Systems Division, Facilities Design and Utilization Engineering Department, Albuquerque, NM., and

Mike O'Neal. Sperry Flight Systems, Sperry Systems Management Engineering Development Staff, FFG Combat Systems Operational Trainer and Combat Systems Operational Team Trainer USN, Ronconcoma, NY.:

> We concurrently feel that the model appears to be a very useful management tool for the Air Force. Its development leads one to believe that viable alternatives can be generated to aid in the decision making process.

No feedback was obtained from the Strategic Systems SPO due to a lack of individuals with the necessary expertise.

RECOMMENDATIONS

The research effort accomplished in this paper has generated the following recommendations for future related research into the simulator placement problem.

1. The model's defined usage costs could be redefined as a new variable cost and the new generated optimal solutions could be compared as to location and number of simulators.

2. Further sensitivity analysis could be accomplished on the usage cost variable to determine when the limits of this parameter no longer allow for an optimal solution.

3. Because the model has cost data which is time dependent, the data should be reevaluated as the data is updated.

4. Once the WST has been adopted and implemented, data could then be evaluated to determine a comparison of optimal solution results and actual results.

5. The WST location problem could be solved using simulation techniques and the results compared to those of this research.

6. No attempt was made to include commander preference in the location solution. However, an attempt at incorporating this and other criteria through a goal programming technique might be accomplished.

7. A methodology to determine the time phasing of

locations into the location scheme would be another area for future research.

APPENDIX A

DESCRIPTION OF LINEAR PROGRAMMING

[This Appendix is taken from (27:50-53).]

Definition

Linear programming (LP) is a mathematical technique for the determination of the best allocation of limited resources. More specifically, LP is a method of solving problems in which a stated objective function must be maximized or minimized within certain constraints. Linear programming techniques are often used as a management tool to allocate limited resources so as to satisfy existing supply and demand constraints (23:224).

Requirements for an LP Problem

Regardless of the definition or specific usage of LP, five basic requirements must be met before the technique can be employed in the solution of a problem (23:224-226).

1. First and most important, a well defined objective function must be formulated. This may be an expression to maximize a profit or to optimize the allocation of limited resources. In all instances, the function must be clearly defined mathematically.

2. Second, alternative courses of action must exist. If they do not, the problem has, in essence, solved itself as the manager really has no choice to make.

3. All equations and inequalities must describe the problem in linear form. This means that all the equations comprising the objective function and the constraints must be of degree one.

4. All relationships between the factors effecting the problem must be expressible as mathematical relationships, either as equalities or inequalities. Simply stated, this requirement specifies that all variables must be interrelated.

5. Finally, resources must be limited. If they are not, the problem is probably not a realistic portrayal of the situation and the solution is meaningless.

Solving LP Problems

Many procedures have been developed to solve LP problems. Simple problems in two variables may be solved graphically (7:95). More complex problems may be solved using Simplex algorithms or computer programs using such algorithms (7:220). The reader should consult any LP text for a more detailed discussion of the exact procedures involved in the solution of these problems.

Advantages of LP Methods

If correctly formulated, an LP problem and solution has many advantages over subjective solutions. Most importantly, an LP solution will indicate the optimal course of action or most effective use of limited resources. Interestingly, a by-product of the solution is that formulation of the problem forces the manager to be objective and to sort out all relevant variables. This may result in an evaluation of which variables are really important and which variables are based on subjective preference only. Finally, the LP solution considers all indicated variables and the bottlenecks caused by the limited nature of the resources involved. Thus, an LP solution is the optimal solution within the constraints identified (23:226).

Limitations of LP Methods

Any representation of reality has its limitations and LP is no exception. Because it is a simplification of reality, problem formulation may not include all relevant variables. Similarly, the relationships assumed may be a function of time and, consequently, must be kept current. The assumption of linearity may also introduce errors into the final result. In short, the solution will be only as good as the validity of the assumptions made and the simplifications used (23:226).

APPENDIX B

BBMIP EXPLANATION

[This Appendix is taken from (20:48-49).]

Conceivably, one could enumerate all possible solutions to the mixed integer problem. Simultaneously constraining each of the x_i to an integer value within its range would be a candidate for the optimal mixed integer solution. If the upper bound on each of the x_i is U_i (U_i integral), then the total number of such problems would be

$$\prod_{i=1}^{n_1} (U_i + 1)$$

and an optimal mixed integer solution would be that one with lowest associated objective function. Unless n_1 and U_i are so small as to make the original problem trivial, such an approach would be prohibitive and one seeks ways to avoid considering some of these resultant problems. Presumably, some of the problems do not have a feasible solution becuase of the integer value assigned to the x_i. Let us consider the x_i one by one and in order, rather than simultaneously. Constrain the first integer variable to an integer level within its range. This yields a linear program which we proceed to solve. Assuming a feasible solution exists, the first variable is held at its designated value and the second variable is constrained in like manner. We proceed in this fashion alternately constraining another variable and solving the resultant program, until either we arrive at a feasible solution having constrained all the x_i, or the integer choices for the variables thus far constrained do not admit a feasible solution. In the first case, we have a candidate for the optimal solution to the original problem. In the second case it makes no sense to proceed, since a linear program obtained by adding a constraint to a "non-feasible" linear program must also be non-feasible. In either case, we make a new choice for the integer value of the latest constrained variable and proceed as before. If we have exhausted the range of the first constrained variable the procedure terminates and the solution with lowest associated objective function is an optimal solution to the mixed integer

problem. In all likelihood, this procedure would cut down considerably the number of linear programs examined as compared to "pure" enumeration.

To continue the analysis, one may eliminate additional resultant problems by making use of information available from the solution of the "feasible" linear programs. First, we notice that as we proceed in a forward direction, the objective function cannot decrease. In effect, we have established a lower bound on the optimal solution to the (partially) constrained problem immediately following each decision point. Once a feasible solution is obtained, it represents an upper bound on the optimal solution to the original problem. Therefore, at any point in the procedure, if the objective function for the (partially) constrained problem equals or exceeds that for the current "best" feasible solution for the original problem, it is unnecessary to examine continuations. . . .

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